AJES
ASIAN JOURNAL OF ENVIRONMENTAL SCIENCE
VOLUME 11 | ISSUE 1 | JUNE, 2016 | 78-86
DOI: 10.15740/HAS/AJES/11.1/78-86
e ISSN-0976-8947
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RESEARCH ARTICLE

Vehicular particulate emissions in Mysore city

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Article Chronicle :
***Received* :**
23.04.2016;
***Revised* :**
04.05.2016;
***Accepted* :**
19.05.2016

ABSTRACT : The study has employed a model to estimate vehicular $PM_{2.5}$ and PM_{10} emission in urban area by calculating vehicles travel on the city roads including registered vehicles in the city and other vehicles from other cities. Data showed that about half million vehicles travel in Mysore city in 2010, and it increased by 100 thousands in 2013. Two-wheelers dominated the city roads into half of the vehicle population followed by four-wheelers and other vehicle categories. All vehicles emit more than 1.5 tonne particulates per day in 2010 for each $PM_{2.5}$ and PM_{10} and it increased by 100 kg for $PM_{2.5}$ and 70 kg for PM_{10} after the next three years. Nearly half of vehicular $PM_{2.5}$ was emitted by heavy diesel vehicles like trucks and buses, while PM_{10} was generated by all vehicle types with almost the same share. Study revealed that vehicular emissions now become major threats in Mysore city.

HOW TO CITE THIS ARTICLE : Fauzie, Azis Kemal and Venkataramana, G.V. (2016). Vehicular particulate emissions in Mysore city. *Asian J. Environ. Sci.*, **11**(1): 78-86, **DOI: 10.15740/HAS/AJES/11.1/78-86.**

Key Words :
Outdoor air pollution, Particulate matter, Vehicular emission, Traffic congestion, PM_{10}, $PM_{2.5}$

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India is experiencing a rapid growth in economic development reflected by industrialization, urbanization, and motor vehicle travel. The increase along with meteorological conditions and population growth influence more to air pollution (CPCB, 2008). Some of its cities even record the highest levels of outdoor air pollution due to particulate matter worldwide (World Bank, 2003).

About two third of air pollution in the urban area is contributed by vehicles (Bhandarkar, 2013). In the last three decades, number of motorized vehicles in India has increased 29-times from 1971 to 2001. The total motor vehicle population in India has increased from about 3 lakhs in 1951 to 89 lakhs in 2006 (CPCB, 2008 and 2010). Urban people tend to have their own private vehicles indicating their high dependency on fossil fuel transportation systems. Transportation activities may represent the increase in people's economic activity, but they bring also notorious effect on increasing street density as well as decreasing ambient air quality and public health (Harish, 2012 and Udayashankara *et al*., 2015).

Air pollution consists of many gaseous and particulate components and varies in chemical composition depending on local environmental conditions (Liu *et al*., 2015). Particulate matter (PM) consists of a mixture of very small particles of dust, pollen, ash, soot, metals, organic and elemental carbon, crustal material, particle-bound water, inorganic ions, polycyclic aromatic hydrocarbons, and biological components such as allergens and microbial compounds (WHO, 2013).

Particulate matter is major concerns in Indian cities due to 60 out of 62 metropolitan cities have exceeded World Health Organization (WHO) standards (Nesamani, 2010). Particulates are generally subdivided into different fractions: less than 10, less than 2.5, and less than 0.1 µm (PM_{10}, $PM_{2.5}$, and

$PM_{0.1}$, respectively). Particulates with diameter between 2.5 and 10 µm are defined as coarse, less than 2.5 µm as fine and less than 0.1 µm as ultrafine particles. Almost all PM emitted by engine-fuelled vehicles consists of fine particles and a large fraction of these particles has an aerodynamic diameter less than 1 µm (Bhandarkar, 2013).

The objective of the study is to estimate emissions of particulate matter in and around Mysore city using a constructed model calculated from vehicular parameters. The study also presents current status and trends of $PM_{2.5}$ and PM_{10} in ambient air quality in the city of Mysore compared to the national standards.

EXPERIMENTAL METHODOLOGY

The study area :

Mysore district is located in the southern part of the state of Karnataka, India and lies at 12° 18' N latitude and 76° 38' E longitude (Fig. A). The district consists of seven taluks namely Krishnarajanagara, Piriyapattana, Hunsur, Heggadadevan Kote, Nanjangud, Tirumakudal Narasipur, and the city of Mysore itself. The city is situated in an undulating surface at 700-900 m above mean sea level, located in-between two rivers Cauvery and Kabini and flanked by Chamundi Hills on the south east. Mysore has a warm and cool and salubrious climate throughout the year. Relative humidity ranges from 21 to 84 per cent and wind speed ranges from 7 to 14 kmph. The weather in winter is cool and the summer is endurable. The temperature in winter is around 16-28°C (from November to February) and in summer is around 21-34°C (from March to June). Mysore gets most of its rain during the southwest monsoon (from July to October) with an annual average of 776 mm (CGWB, 2012; Harish, 2011 and 2013).

Rapidly developing its urban area including in terms of demography, migration, transportation and industrial sector, Mysore has projected to be second metropolitan city in Karnataka after Bangalore. The city has 785,800 populations as per 2011 census. With area spread over 128 sq km, the population density of the city is 6,139 per sq km about 14 times higher than population density of the district (Harish, 2011; DCO, 2011 and CGWB, 2012).

Measurement of PM concentration in ambient air:

As per national ambient air quality standards, every country usually conduct PM monitoring in their location, either manually every period of time or continuously using

Table A : Emission factors for two wheelers, three wheelers, cars, buses, LCV and HCV (g/km)

Vehicle types	Fuel types	Emission Factors for $PM_{2.5}$[a]				Emission Factors for PM_{10}[b]						
		<2001	Euro-I	Euro-II	average	<1996	<2001	Euro-I	Euro-II	Euro-III	Euro-IV	average
2W	2S-G	0.06	0.06		0.038	0.23	0.1	0.05	0.05			0.083
	4S-G	0.015	0.015			0.07	0.06	0.05	0.05			
3W	2S-G	0.1			0.075	0.35	0.15	0.08	0.08			0.188
	4S-G	0.015						0.11[c]	0.015[c]			
	2S-CNG							0.118[c]				
	4S-CNG		0.11					0.015[a]				
	2S-LPG[c]						0.171	0.13				
	D[c]						0.782	0.347	0.091			
Cars	PCG	0.026	0.005	0.005	0.060	0.06	0.05	0.04	0.03	0.02	0.016	0.175
	PCD	0.24	0.077			0.84	0.42	0.14	0.07	0.05	0.05	
	CNG			0.007			0.001[c]	0.006[c]	0.007[a]			
	LPG[c]							0.002				
	MUVD[c]					0.57	0.56	0.48	0.096			
Buses	D	1.21	0.97		0.773	2.013[c]	1.213[c]	0.56	0.24	0.24	0.22	0.566
	CNG		0.14					0.044[c]	0.0065[d]			
LCV	D	0.62	0.49	0.19	0.332	0.8	0.5	0.2	0.07	0.05	0.025	0.239
	CNG			0.026					0.026[a]			
HCV	D	1.22	0.97		1.095	1.5	0.8	0.28	0.12	0.1	0.06	0.477

where, 2W = two wheelers, 3W = three wheelers, 2S = two stroke, 4S = four stroke, G = gasoline, D = diesel, CNG = compressed natural gas, LPG = liquefied natural gas, PCG = passenger cars gasoline, PCD = passenger cars diesel, MUVD = multi utility vehicles diesel, LCV = light commercial vehicles, HCV = heavy commercial vehicles.

Sources: [a] Kumari *et al.*, 2013; [b] Goyal, 2007; [c] ARAI, 2008 and [d] Roychowdhury, 2010.

data-logging system. There are two ambient air quality monitoring centres in Mysore – one located at K.R. circle near sub-urban bus stand and the other at KSPCB office near Hebbal industrial area (Fig. A). Air quality measure at K.R. circle represents the pollution level in residential and commercial area caused by vehicular traffic, while the one at Hebbal measures industrial pollution. The measurement employs conventional high volume air samplers for collecting $PM_{2.5}$ and PM_{10} at both locations. Gravimetric analysis is used to determine the mass concentration of each parameter in the ambient air by taking difference between final and initial weight of filter papers and dividing by the volume of air sampled (Udayashankara *et al.*, 2015).

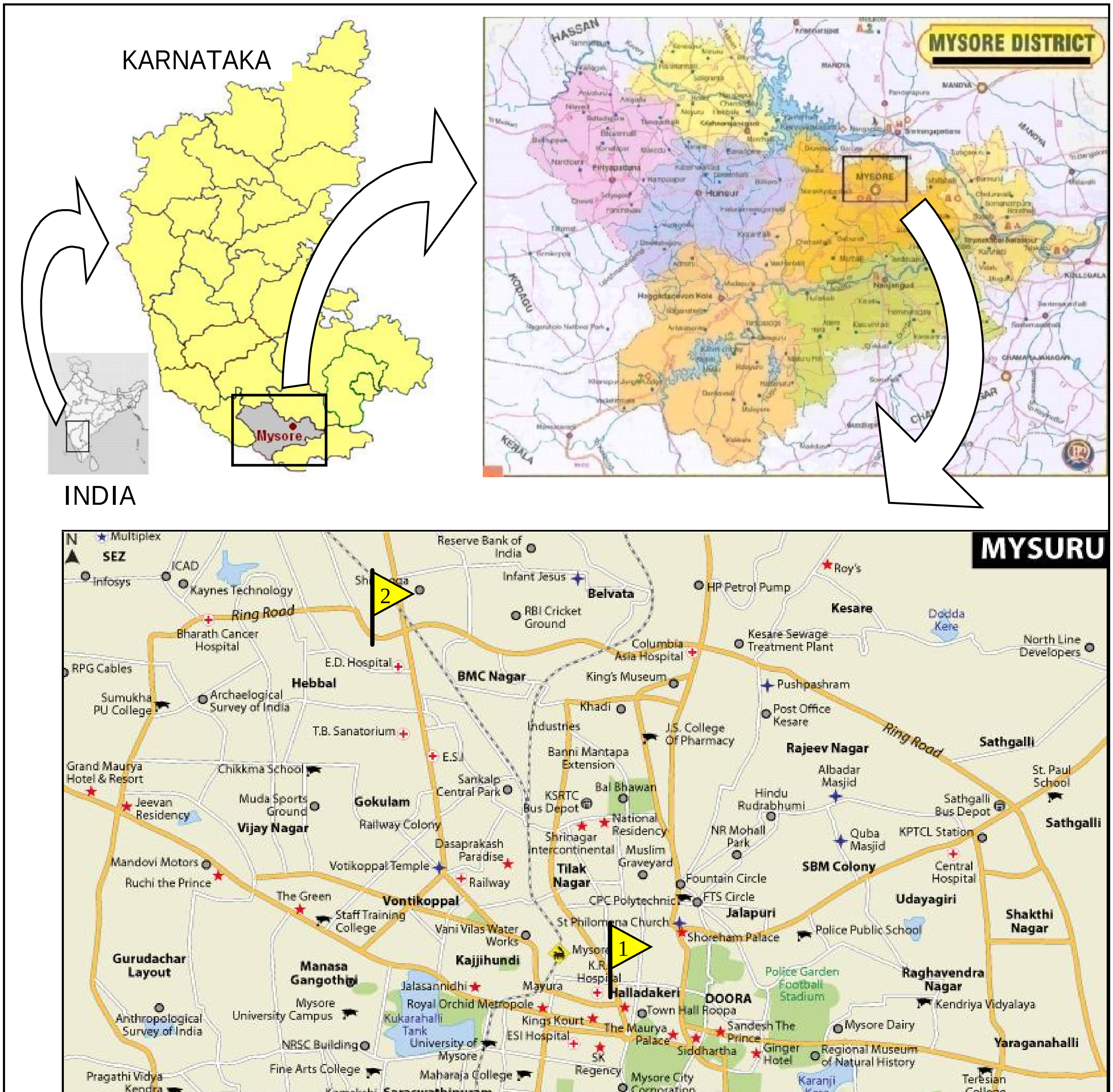


Fig. A : Locations for ambient air quality sampling in (1) commercial area and (2) industrial area

Estimation of vehicular PM emission :

Estimation of PM emission affected air pollution in the city is calculated merely from vehicular aspects such as number of vehicles and road length. The daily emission estimate of particulate matter in a given year in the city was calculated by using the following formula (Ramachandra and Shwetmala, 2009 and Kumari *et al.*, 2013):

$$\mathbf{E_{ijk}} = \sum_{j=1}^{n} \sum_{k=1}^{6} (\mathbf{N_{ijk}} \times \mathbf{D_{ijk}} \times \mathbf{EF_k}) \quad (1)$$

where,

subscripts i represent the year, j is the respective road segment, and k is the respective vehicle category.

E_{ijk} = daily emission of PM in year i caused by vehicle category k travelled through road segment j (g).

N_{ijk} = daily number of vehicles in year i, of category k, and travelled through road segment j.

D_{ijk} = distance of road segment j in year i travelled by respective vehicle category k (km).

EF_k = emission factor of vehicle category k (g/km).

n = number of road segments in either state highways or major district roads.

Emission factors (EF_k) calculated in Eq. 1 are differentiated for estimating $PM_{2.5}$ and PM_{10}. EF_k for PM_{10} are originally used to calculate all different size of PM from 0.056 to 18 microns ($PM_{0.056}$ to PM_{18}). Since PM_{18} includes PM_{10} fractions and share of PM_{10} is much larger in PM_{18} as compared to other smaller fractions, so the factors are then used to estimate PM_{10} emissions. EF_k for both $PM_{2.5}$ and PM_{10} were taken as average values of emission factors mentioned in several sources by considering vehicle types, fuel types and year of norms or compliance class based on technology like uncontrolled EF (upto 2000), Euro-I to Euro-IV – or in India sometimes referred to as Bharat Stage-I (BS-I) to BS-IV (Goyal, 2007; ARAI, 2008; Roychowdhury, 2010 and Kumari *et al.*, 2013). Based on vehicle category, $PM_{2.5}$ emission factors for two wheelers, three wheelers, cars, buses, LCV, and HCV are 0.038; 0.075; 0.06; 0.773; 0.332; and 1.095 g/km, respectively, whereas PM_{10} emission factors are 0.083; 0.188; 0.175; 0.566; 0.239; and 0.477 g/km, respectively (Tabel A).

EXPERIMENTAL FINDINGS AND DISCUSSION

The findings of the present study as well as relevant discussion have been presented under following heads :

Road traffic in Mysore :

Government of Karnataka Public Works, Ports and Inland Water Transport (PWPIWT) Department (2010, 2013) conducted road traffic surveys from all cities in Karnataka and categorized vehicles into different criteria including two-wheelers, auto rickshaw, cars and jeeps, vans and tempos, minibuses, buses, light commercial vehicles (LCV), goods vehicles (with 6, 10 and more than 10 tyres) and tractors with trailers. In this present study, vehicles are differentiated into six categories consist of two-wheelers (2W), three-wheelers (3W), cars, buses, LCV, and heavy commercial vehicles (HCV). Here cars also include jeeps, vans and tempos; buses also include minibuses; LCV also includes tractors with trailers; and HCV category comprises all types of goods vehicles. The actual number of motor vehicles use may be lower, as office registration procedures do not remove many of the out of service vehicles from the records. In fact, about 60 per cent of vehicular pollution in India is caused by old and less-maintained vehicles (Pundir, 2000 and Nesamani, 2010). Road traffic survey reports from PWPIWT Department – or often called as Road Transport Office (RTO) – were then analyzed to

Table 1: Number of registered vehicles and number of vehicles travelled daily in Mysore

Vehicle category	Number of registered vehicles in Mysore*		Number of vehicles** travelled daily through			
			state highways		major district roads	
	2010	2015	2010	2013	2010	2013
2W	351,074	439,774	120,379	114,979	114,691	145,052
3W	17,155	20,745	35,373	32,638	32,923	32,516
Cars	49,180	46,583	60,319	73,800	34,816	45,590
Buses	9,594 (Buses, LCV, HCV)	16,251 (Buses, LCV, HCV)	22,356	26,842	7,082	8,946
LCV			19,583	34,259	14,590	24,226
HCV			32,401	37.528	12,843	16,854
Total	438,003	523,352	290,411	320,046	216,945	273,184

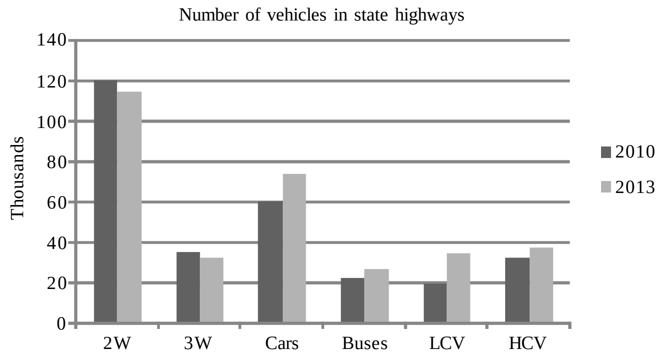
Sources: * Harish, 2013; ** calculated from PWPIWT Department, 2010 and 2013.

see road traffic profiles in Mysore city from 2010 to 2013 as basis data to calculate vehicular emission of PM.

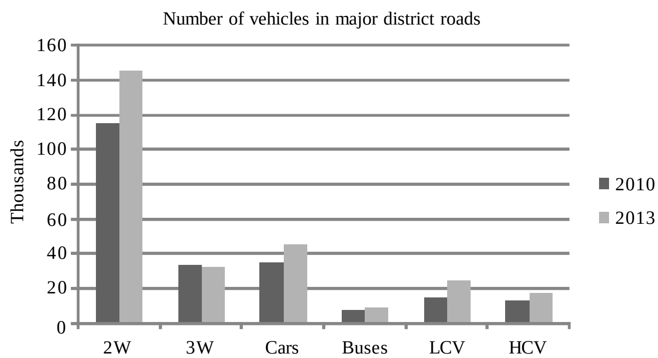
There are more than 400 thousand vehicles registered in Mysore in 2010 and are projected to be 500 thousands in 2015 (Table 1). The two-wheelers account the largest number of the total vehicles in 2010 (82%) and followed by four-wheelers including cars, jeeps and taxi which account for about 12 per cent of total vehicles. Three-wheelers and trucks/buses account for about 4 and 2 per cent, respectively (Harish, 2013). The road traffic surveys conducted by RTO officers found over 500 thousand vehicles travelled through Mysore city daily in 2010; 290 vehicles travelled through state highways and the rest counted only in major district roads. This figure increased to almost 600 thousand vehicles in 2013. This is due to vehicles travelled in Mysore were not only Mysore registered vehicles. Some of them came from neighbouring cities or states, and they also contribute much on air pollution in the city. So the PM emissions may be higher in the Mysore city.

In Mysore, the two-wheelers dominate the state highways and other major district roads that accounted mostly half of the vehicle population in either 2010 or 2013. The number was followed by cars that accounted for about one fifth in state highways and 16 per cent in district roads. Population of passenger cars, trucks and buses were more in state highways than in district roads. Heavy commercial vehicles or trucks occupied 11 per cent of total vehicles and buses existed about 8 per cent on state highways, whereas on other major district roads buses occupied only 3 per cent of total vehicle types and trucks only 6 per cent. Three-wheelers accounted almost the same number in these two sampling time particularly in major district roads (Fig. 1).

The growth of vehicles travelled in Mysore city roads was increasing from 2010 to 2013, and the number was very significant for two-wheelers. Although number of two-wheelers presented on state highways felt down about five thousand units in 2013 [Fig. 1(a)], but on most of major district roads it increased drastically for about 30 thousand units [Fig. 1(b)]. On the other hand, population of three-wheelers slightly reduced during this 3-year period particularly on state highways.



(a)



(b)

Fig. 1 : Daily number of vehicles travelled through Mysore (a) state highways and (b) major district roads

Vehicular PM emissions in Mysore :

Number of vehicles travel along particular city roads (N_{ijk}) and their distances, somehow, affects on the estimation of air pollutant emissions. PM and other gaseous pollutant emissions is usually estimated from

Table 2 : PM emissions estimates from vehicles travelled daily in Mysore in 2010 and 2013

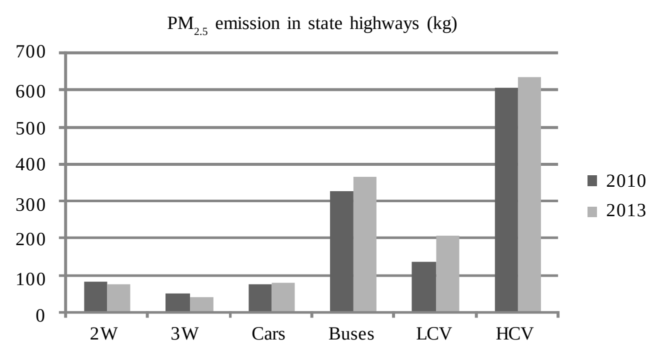
Vehicle category	$PM_{2.5}$ emissions (kg) from vehicles travelled in				PM_{10} emissions (kg) from vehicles travelled in			
	state highways		major district roads		state highways		major district roads	
	2010	2013	2010	2013	2010	2013	2010	2013
2W	82.68	74.33	47.58	57.93	181.89	163.53	104.68	127.44
3W	47.84	38.74	27.18	26.45	119.68	96.92	67.98	66.15
Cars	73.69	77.76	26.61	29.20	215.43	227.31	77.80	85.37
Buses	323.89	364.52	76.10	71.03	237.18	266.94	55.73	52.02
LCV	134.32	203.33	51.45	82.06	96.73	146.42	37.05	59.09
HCV	604.41	634.34	137.19	195.74	263.11	276.14	59.72	85.21
Total	1266.83	1393.02	366.11	462.40	1114.02	1177.26	402.96	475.27

vehicles registered in that city only. Every registered vehicle in each category was assumed to travel the same distance in daily basis. Further consideration should be taken for vehicles travel a lot daily and for others that mostly stand at homes or garages. Kumari *et al*. (2013) used average annual vehicle kilometre travelled (AVKT) to estimate PM emissions for respective vehicle categories. Harish (2012) assumed that two and four wheelers travelled 12 km a day, while three-wheelers and trucks/buses travelled 35 and 52 km a day, respectively. Moreover, the presence of outsiders' vehicles that also travelled along Mysore city roads should also be considered. In this study, distance of road segments travelled by respective vehicles (D_{ijk}) is used instead of calculating AVKT. Length of each road segment was provided by PWPIWT Department (2010 and 2013) that correspond to roads or highways in Mysore city occupied by all respective vehicle types. RTO officers count number of vehicles travelled on each road segment in different vehicle categories. Total length of all state highways in and around Mysore city is more or less 700 km with average distance per segments is about 16 km, while length of all major district roads is approximately 900 km with 9 km average per road segments.

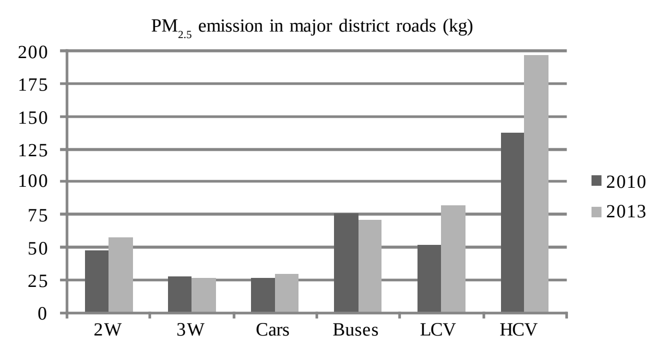
All parameters including number of vehicles (N_{ijk}), distance of road segments (D_{ijk}) and emission factors (EF_k) were then calculated resulting number of array data subjected for each vehicle category as daily emissions estimates for $PM_{2.5}$ and PM_{10}. The results in unit grams were then converted into kilograms. Results showed that total emissions of each parameter ($PM_{2.5}$ and PM_{10}) from all vehicles travelled on state highways in 2010 were more than one tonne per day, whereas on major district roads were nearly 400 kg per day. These values increased about 100 kg for $PM_{2.5}$ and 70 kg for PM_{10} in 2013 (Table 2). It was convinced that state highways received more particulates from vehicles than district roads. These numbers accounted for particulate emissions only from vehicular exhausts and did not consider other non-exhaust emissions such as from tyre wear, break wear and road surface wear (Kumari *et al.*, 2013).

The larger vehicles such as trucks and buses dominated the sources of $PM_{2.5}$ emissions in either state highways or district roads as compared to smaller vehicles (Fig. 2). About 40 per cent of $PM_{2.5}$ was emitted by HCV. But this fact did not followed by PM_{10} which has more diverse sources of emissions including from small vehicles like passenger cars and 2 or 3 wheelers [Fig. 3 (a)]. Two wheelers even dominated the PM_{10} emissions from their exhausts in major district roads both in 2010 and 2013 with values more than 100 kg per day [Fig. 3(b)]. It is probably due to source of $PM_{2.5}$ emissions is mostly from diesel fuel like buses and trucks usually used. Exhausts from diesel-fuelled vehicle contain more heavy metals such as lead, cadmium, copper, chromium, nickel, selenium and zinc, and they mostly fall in the $PM_{2.5}$ size range (ARAI, 2008). On the other hand, vehicles with other fuels like gasoline, CNG and LPG did not emit more $PM_{2.5}$ as much as PM_{10}.

High number of specific vehicle category travelled through the roads (N_{ijk}) does not mean that PM emission (E_{ijk}) from that vehicle category is also high. Two-wheel motorbikes and four-wheel cars that occupy high number on both road types apparently only contribute less to ambient particulate emission, particularly $PM_{2.5}$. On contrast, diesel trucks (HCV) and buses that exhibit less number on the roads emits huge amount of $PM_{2.5}$ from their exhausts (Fig. 2). The emission factors (EF_k) are the dominant parameters to determine the quantity of particulate emission from road transport.

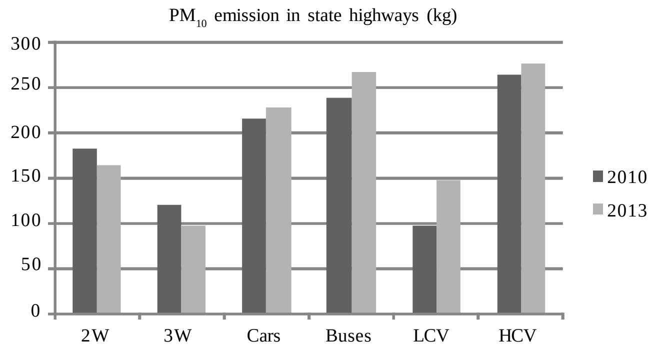


(a)

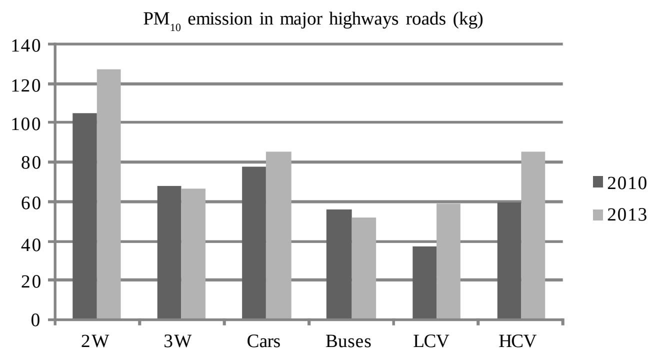


(b)

Fig. 2 : Daily estimates of $PM_{2.5}$ emissions (in kg) from vehicles in (a) state highways and (b) major district roads



(a)



(b)

Fig. 3 : Daily estimates of PM_{10} emissions (in kg) from vehicles in (a) state highways and (b) major district roads

Trucks and buses usually consume diesel fuels, while majority of motorbikes and passenger cars are gasoline-fuelled. Gasoline-fuelled vehicles have lower emission factors than diesel-fuelled vehicles (Goyal, 2007; ARAI, 2008 and Kumari *et al.*, 2013). PM emissions from gasoline-fuelled vehicles result from unburned lubricating oil and ash-forming fuel and oil additives. PM emitted by diesel-fuelled vehicles consists of soot formed during combustion, heavy hydrocarbon and sulphates (Bhandarkar, 2013). Moreover, trucks and buses running on the roads are mostly old vehicles, poorly-maintained and carry more than the permitted load of passengers and goods resulting on higher levels of gaseous and particulate emission from their exhausts (Harish, 2012).

Status of PM in Mysore ambient air quality :

PM holds important role in ambient air quality. It has more potential sources of emission than other parameters like carbon monoxide, sulphur dioxide, nitrogen dioxide, and ozone. PM is often identified in ambient air even there is no industry in the city or other combustion process that usually emits pollutants. PM is also considered to be important hazard because of its high impacts on public health degeneration which is found to be major cause of respiratory and cardiovascular diseases (CPCB, 2008 and Anderson and Thundiyil, 2012).

In Mysore city, PM_{10} exhibits similar value for commercial and industrial area in 2012 which is 71 µg/m^3 (Fig. 4) and it was higher than permissible annual average concentration of PM_{10} that sets on 60 µg/m^3 according to Revised National Ambient Air Quality Standards (NAAQS) released by Government of India on 18th of November, 2009 (CPCB, 2009 and 2011). Then in the next two years PM_{10} concentration in industrial area starts increasing to certain value exceeding the value of SPM in commercial area for about 4 µg/m^3 in 2013 and 10 µg/m^3 in 2014. Lastly, in recent data (2015) the trend is then flip over. Concentration of PM_{10} in industrial area is now becoming much lower as compared to such value in commercial area. Commercial area is exposed by particulate emission nearly close to the threshold limit and it is very much higher than in industrial area due to higher growth of vehicle number and emergence of traffic congestion in the city centre roads. Traffic congestion contributes greater in deteriorating environment. In the last decade, about 70 per cent of ambient-air quality degradation in Mysore is affected by transportation activities (Harish, 2012 and 2013).

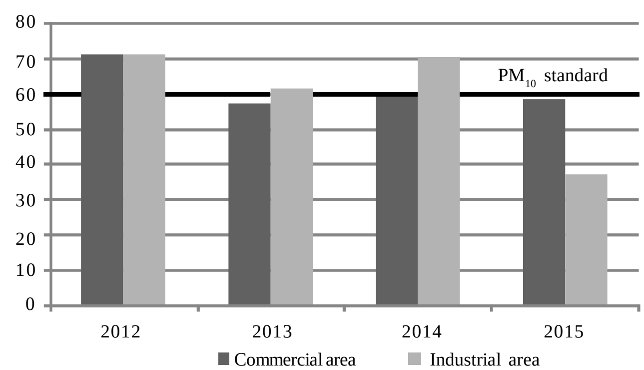


Fig. 4 : PM_{10} concentrations (in µg/m^3) in Mysore city's commercial and industrial area

Presence of $PM_{2.5}$ in ambient air highly threatens human health due to fine particles can travel and deposit deeper into lower respiratory tract and lungs causing cardio-respiratory health problem (World Bank, 2003 and Bhandarkar, 2013). Therefore, rather than just monitoring SPM or PM_{10} status, measurement of $PM_{2.5}$ concentration in ambient air now becomes an important task for government or municipalities in either developing or

developed countries. KSPCB Mysore also manages to measure $PM_{2.5}$ concentration at the same sampling locations in the city as PM_{10} measurement usually conducted.

Concentration of $PM_{2.5}$ monitored was very much lower than concentration of PM_{10} on the same sampling years and at the same sampling locations (Fig. 5). In 2012, both PM_{10} and $PM_{2.5}$ exceeded the permissible limits. PM_{10} was 11 units higher than the annual average standard, whereas $PM_{2.5}$ was 50 per cent higher than the limit according to NAAQS that stands on 40 µg/m^3 (CPCB, 2009 and 2011). In 2013 and 2014, the differences between PM_{10} and $PM_{2.5}$ values were very much higher than in 2012. PM_{10} concentration in 2013 touched the standard limit (60 µg/m^3), while in 2014 the value again exceeded the limit for about one-sixth of the national standard. The annual average values of $PM_{2.5}$ monitored in 2013 and 2014 nearly halve the ambient air quality standard.

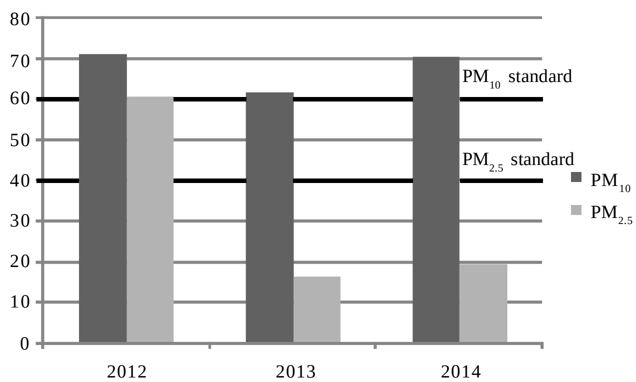


Fig. 5 : PM_{10} and $PM_{2.5}$ concentrations (in µg/m^3) in Mysore city's industrial area

Conclusion :

The study shows that the current status of particulate emission in Mysore city threatens ambient air quality and public health in the city. Recent studies clearly documented that number of vehicles registered and travelled in Mysore city roads increasing highly and continuously every year, mostly two-wheelers that accounted half of the vehicle population. To estimate particulate emission particularly from vehicle exhausts, a model has been constructed by considering all vehicles travel on the city roads including ones registered in the city and guest vehicles from other cities or states. It shows that emission factors from diesel fuels affect more in high number of $PM_{2.5}$ emitted, while all vehicle types contribute almost the same to PM_{10}. Annually average measurement of $PM_{2.5}$ and PM_{10} conducted in either industrial or commercial area in Mysore city shows high values that reaching national ambient air quality standards and at some point exceeding the permissible limits.

Acknowledgement :

Authors wish to thank Karnataka State Pollution Control Board (KSPCB) Mysore for providing the ambient air monitoring data series from 2012 to 2015. Authors also wish to thank Government of Karnataka Public Works, Ports and Inland Water Transport Department for providing the road traffic survey report data in 2010 and 2013.

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